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ARTESIAN WELL SECTIONS AT ITHACA, N, Y.[1]

THE WELLS.[2]

DURING the typhoid epidemic at Ithaca, N. Y., in 1903, a committee of citizens began explorations for a source of artesian water to replace the surface supply then in use. This work was continued by the Ithaca water board, and the result was the sinking of thirteen wells in a limited area on the southern outskirts of the city. Prior to this an artesian well had been developed in the same area, yielding a daily flow of about 300,000 gallons from a series of Pleistocene gravels at a depth of about 280 feet. A majority of the new wells found water in what appear to be the same gravels; others failed to develop water.

Besides these deep wells, there are a large number of shallower ones in the city of Ithaca which obtain artesian water in a gravel series found at depths usually from 50 to 100 feet.

[1]Published by permission of the Director of the United States Geological Survey.

I am indebted for valuable assistance in the preparation of this paper to the following gentlemen: Mr. C. C. Vermeule, engineer in charge of the boring of the wells, for directing that samples be preserved for me; Mr. F. L. Getman, his assistant, for collecting the samples and for other valuable information; Mr. Lawrence Martin, of Cornell University, for aid in gathering information, and in consideration of the nature of the well sections; Dr. G. K. Gilbert, for placing at my disposal certain facts from his notebooks bearing upon the question of tilting of the land in central New York; Dr. William H. Dall, for identifying the mollusca; and Professor D. P. Penhallow, for identifying the plant remains.

[2]A more detailed statement of the bearing of this exploration on local water supply will be published by the U. S. Geological Survey.

IMPORTANCE OF THESE WELLS.

These wells have yielded three important geological results: (1) They have in two cases revealed the exact depth of filling by Pleistocene deposits, and have therefore given some additional facts concerning the form and depth of the Cayuga Valley. (2) Since samples were collected at frequent intervals in several of the wells, and records kept of all, they have revealed the structure underlying the Ithaca delta down to the rock floor. (3) They have thrown some light on the occurrence of artesian water in Pleistocene deposits.

DEPTH OF DEPOSITS.

The wells are all located near the western margin of the delta on which the main portion of the city of Ithaca is built. The surface soil is clay and muck, and the region is evidently one reclaimed from Lake Cayuga by the same processes of lake filling that are now at work on the outer edge of the delta on the north side of the city. While low and swampy throughout much of its area, this nearly level delta rises perceptibly toward the creeks that descend through gorges cut in the valley walls. These elevated sections are low, flat alluvial fans, raised above the general delta level by deposits brought down by the torrential streams that occupy the hillside gorges.

The delta also rises gently toward the south, and at a distance of about two miles south of Ithaca abruptly ends against the north face of the morainic complex which fills the valley thence to its present divide. It is evident that this moraine descends beneath the delta deposits.

Two of the borings reached bed-rock, one (Fig. 1, *C*) at a depth of 260 feet, the other (Fig. 1, *G*) still further out in the valley, at a depth of 342 feet. A profile of the valley at this point is shown in Fig. 2. Farther north (Fig. 1, *A* and *B*) two wells, bored to the underlying salt, encountered rock at 430 and 401 feet respectively, the latter being 1,500 feet south of the former.

These borings are not numerous enough to warrant any conclusions further than that the maximum depth of the valley is at least 430 feet below the delta at Ithaca, or about 25 feet below sea-level. Since soundings in Lake Cayuga reveal a depth of 435 feet in the deepest point, in which, of course, there is at least some filling, the borings at Ithaca do not add to the known depth of the valley. It is not to be inferred, however, that the deepest boring at Ithaca, although near the middle of the valley, really represents the deepest part of the valley in this region.[1] The discovery of rock in these wells shows that the general slope of the lower valley walls is continued down with practically no change (Fig. 2), at least to the depth reached in the artesian wells (Fig. 1, *C* and *G*).

FIG. 1.—Section of the "Ithaca Sheet" (U. S. Geological Survey) to show the location of the artesian wells. *A*, *B*, salt wells, rock at 430 and 401 feet respectively; *C*, Strang Well, No. 1, 286 feet, struck rock at 260 feet; *D*, Millard Well, No. 2, 259 feet; *E*, Old Clinton St. Well, 280 feet; *F*, South Well, 232 feet; *G*, Strang Well, No. 2, 352 feet, struck rock at 342 feet; *H*, Trapp Well, 332 feet; *I*, Holmes Well, 291 feet; *J*, Millard Well, No. 1, 303 feet; *K*, several wells, close together, as follows: Illston Well, 286 feet; Strang Well, No. 3, 280 feet; Strang Well, No. 4, 279.9 feet; Strang Well, No. 5, 276 feet; and Strang Well, No. 6, 295 feet; *L*, Millard Well, No. 3, 303 feet.

DESCRIPTION OF THE WELL SECTIONS.

Both in the deeper artesian wells and in shallow ones in the city of Ithaca the upper layers are found to be a fine-grained, massive clay. In two cases it is reported as sandy. This clay layer is absent, or at least not continuous, near the eastern wall of the valley where alluvial fans have been built opposite the stream mouths. The depth of the clay stratum varies from approximately 40 to 60 feet. Fragments of mollusca and plant fragments, including pieces of reeds and wood, were found in several of the samples from this clay layer; and in two cases logs were encountered, one at 38–39 feet, another at 33 feet.

[1] It is noteworthy, in this connection, that a well near the center of the Seneca Valley at Watkins had not reached the bottom of the drift deposits at a depth of 1,080 feet.

Beneath this clay layer, in every well of which there is a record, a series of coarser beds is found. These coarse beds vary greatly even in neighboring wells; but in most cases there are both sand and gravel layers. The bottom of the series of coarse sediments varies from 60 to approximately 120 feet, and the thickness in individual wells from 20 to about 70 feet. The coarser sands are clear and well washed; the gravels consist of well-rounded pebbles similar to those now brought down by the torrential creeks that enter the valley.

In most of the samples preserved from these coarse layers plant fragments and mollusca were found. Seven logs were encountered, and the two logs found in the overlying clays were almost down to the level of the coarser series. Thus between the depth of 35 and 119 feet nine logs were encountered in boring thirteen six-inch wells. Since two of the wells passed through two logs each, logs were encountered in seven out of thirteen wells. The depth of the several logs is given in the following table:

Wells	Depth in Feet	Material
Strang	56 -58	Gravel
Old Clinton St	63	Sand
Millard 3	38 -39	Clay
Millard 3	118 -119	Sand
Trapp	48½-50½	Gravel and sand
Trapp	55½-56½	Gravel and sand
Millard 1	50 -51½	Sand and pure gravel
South	33	Clay, somewhat sandy
Strang 3	110 -112	Probably at bottom of gravel

In all the deep wells the coarser layers are underlain by a great thickness of clay, in which no molluscan remains were found, though in several samples small, indefinite plant fragments occur. In most of the wells the driller failed to preserve more than one sample, which he considered typical of the entire clay mass; but near the top and bottom of the series the material is occasionally reported as "clay and stone," "clay and gravel," or "clay and sand." In one well (the south well), however, samples were preserved every ten feet, and these samples show clearly the nature of the material. From top to bottom, that is, from 70 to 200 feet, it is a fine-grained clay, at all depths lower than 100 feet containing small angular pebbles, in some cases scratched. These stones increase in number and size toward the bottom, and the proportion of sand increases to such an extent that below the depth of 135 feet the well-driller calls it a sandy clay. But down to the 200-foot level the stratum is unquestionably clay.

Owing to the indefiniteness of the nomenclature used by well-drillers, and the failure in many cases, to preserve samples it is not always easy to state exactly where the bottom of the clay series is. Using the best judgment possible, I place the base of the clay series in the thirteen wells as follows: 220, 210–30, 262–76, 238–78, 230, 225–76, 200, 214–80, 202–22, 244–70, 240, 242–46, 234–70. The well which gives the 200-foot level for the bottom of the clay is the one from which most samples were obtained, and for that point may be accepted as correct. It is, however, the farthest south of all the wells, and it does not follow that the bottom at that point is the same level as the bottom at other points. On the contrary, all the evidence seems to indicate that the base of the clay series is decidedly irregular.

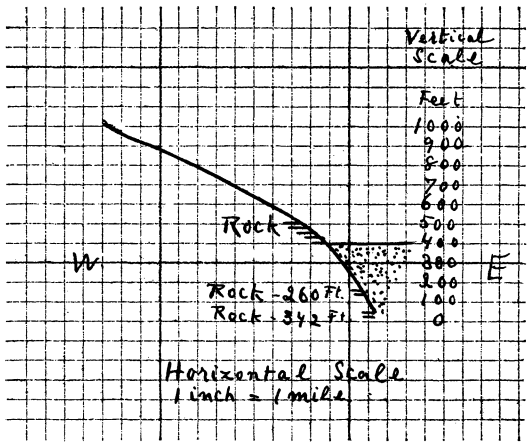

FIG. 2.— Profile of the hill slope on the western side of the Cayuga Valley at Ithaca just west of the artesian well sites. This profile is continued down to the points where rock was reached in the artesian wells. (Horizontal scale, 1 mile to the inch; vertical scale, 1,000 feet to the inch.)

As the base of the clay series is approached, and after it is certainly passed, a series of beds of marked irregularity is encountered. They are prevailingly coarse-textured, and in every well include some sand or gravel. In many of the wells

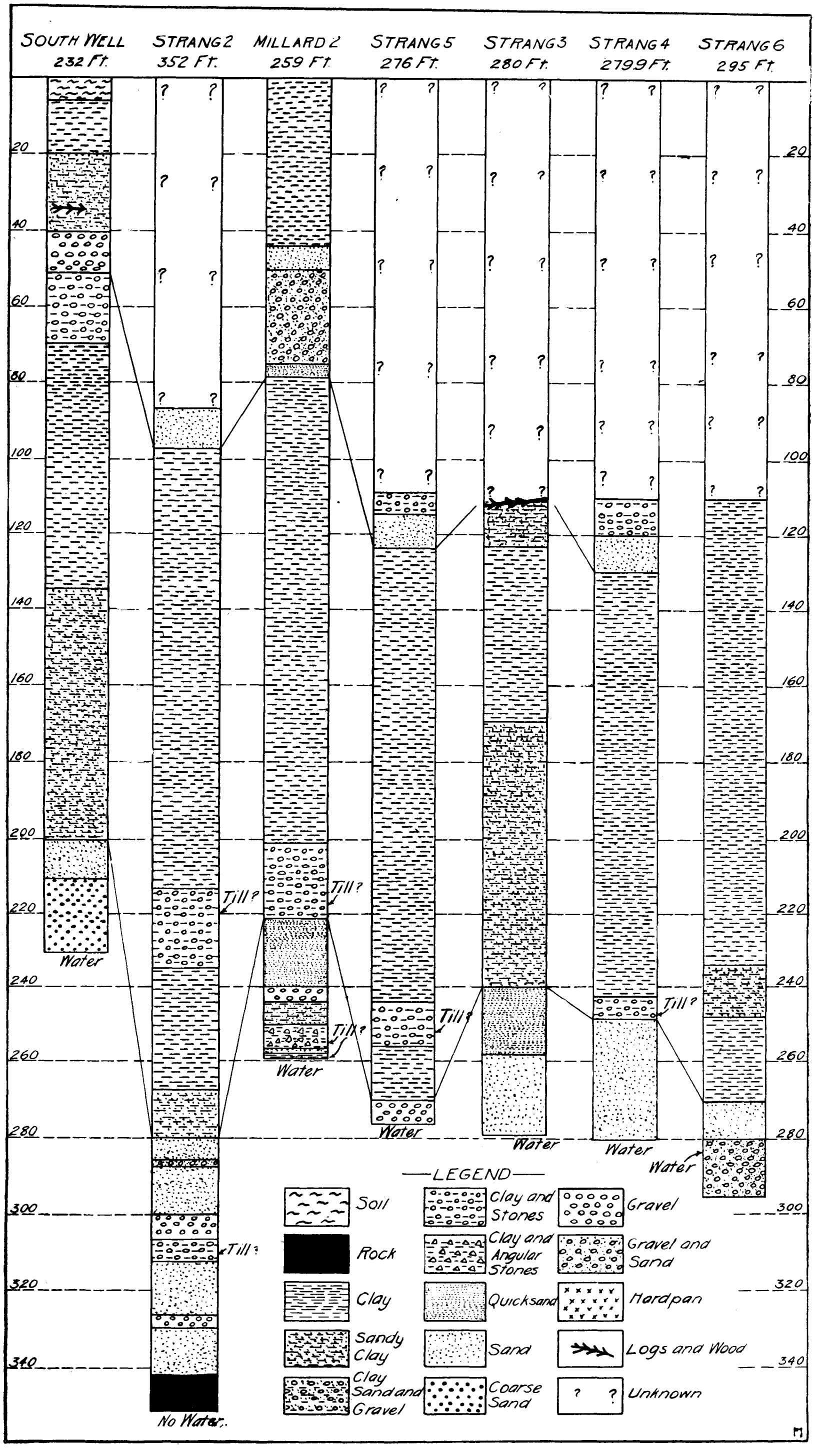

FIG. 3.—Sections of seven artesian wells grouped approximately along a north-south line. South well, southernmost. Limits of the four series of deposits indicated in a general way by the lines connecting the different sections.

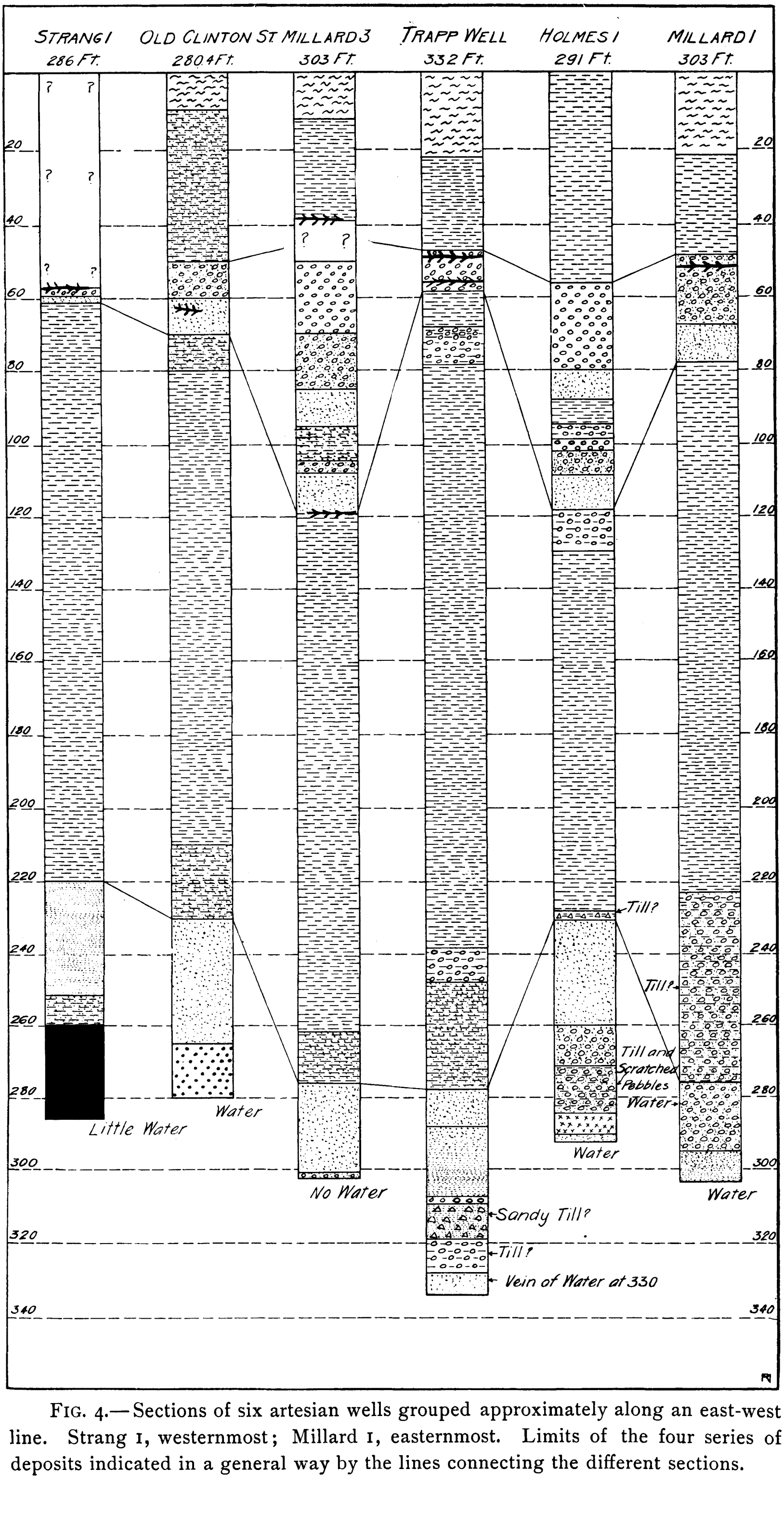

FIG. 4.—Sections of six artesian wells grouped approximately along an east-west line. Strang 1, westernmost; Millard 1, easternmost. Limits of the four series of deposits indicated in a general way by the lines connecting the different sections.

both sand and gravel are encountered. No two of the wells have the same sequence of layers, even though the wells are close together. Samples prove that some of the layers are water-washed sand and gravel, while others are unquestionably till, with scratched stones. In a number of other places till is suspected, though the evidence is not sufficient to prove it.

In this series of coarse deposits, water is found at varying depths in the different wells, and in different sediments. In some cases it is found in a sandy clay, called "quicksand," in which there is so much water, under such pressure, that the sand is forced into the pipes in sufficient quantities to fill them and stop the water flow. Between this extreme and that in which the water is found in coarse gravel, there are several intermediate conditions. The largest flow is obtained from the coarse gravels.

Beneath the unquestioned till, and in various places beneath the materials interpreted as probable till, is found a black sand in which from 50 to 75 per cent. of the material is quartz, the remainder being mainly dark shale fragments. In one of the wells that reached bed-rock this black sand rests on the rock, which was encountered at a depth of 342 feet. Neither here nor in the other well that reached rock, nor, in fact, in any of the wells, was any older drift encountered. All the materials are such as might have been brought by the last ice advance, or deposited since the ice-sheet melted away. Whether deposits of earlier ice advances were never made here, or whether they were all swept away by the last ice advance, is not determined by the evidence.

INTERPRETATION OF THE WELL SECTIONS.

Morainic lower series.—The history of the accumulation of the 342 feet of sediment revealed by these well-borings is in most respects clear. That the bottom series of till, sand, and gravel is morainic seems proved by several facts: (1) the neigborhood of the massive moraine which rises above the delta two miles south of the wells; (2) the position of the coarse materials at the base of the series, from all other members of which they differ decidedly; (3) the apparently irregular outline of the upper portion of this lower series of coarse materials; (4) the marked variety of materials composing the lower series, which vary from gravel and sand to till, thus closely resembling the moraine that rises to the surface farther south; (5) the large percentage of water-washed material, again resembling the condition in the moraine farther south. This large amount of water-washed material would be expected where the ice-front stood in a deep lake, as was the case here.

Glacial lake clay.—It is well established by the evidence of various overflow channels, by well-defined elevated deltas at various levels,[1] and by lake clays on the hill slopes, that the Cayuga Valley was occupied by a steadily expanding, ice-dammed lake, with its level frequently lowered as successively lower outlets were discovered by the melting back of the receding ice-sheet. This lake condition lasted for a long time; in fact, until the Mohawk outflow was discovered. The length of this period of lake stage cannot be stated; but it was sufficient for the ice to have melted back at least forty miles. Of necessity a great amount of clay must have been deposited in this lake, not merely that supplied from the glacier, but that washed from the hill slopes, and that brought by the streams which descended the steep hill slopes.

The great thickness of clay found in all the wells, usually between the 100 and 200-foot levels, is interpreted as lake clay deposited in this ice-dammed lake. The great thickness of the clay stratum, its uniform character, its occurrence in all the wells, the general absence of animal remains and the presence of only minute fragments of plants, the occurrence of scratched pebbles that might have been ice-borne, and the increasing coarseness of the clay toward the bottom, all harmonize with this interpretation. No opposing facts were discovered.

Recent lake clays.—The uppermost clay beds, between the 0 and 40–50-foot levels, with abundant organic remains and an almost complete absence of sand and pebbles, are interpreted as lake

[1] See papers by FAIRCHILD, *Bulletin Geological Society of America*, Vol. VI (1895), pp. 353–74; Vol. X (1899), pp. 27–68; and by WATSON, *New York State Museum Report 51* (1897), Part I, r 55–r 117.

clays formed in the same manner as those now accumulating. They are believed to represent modern lake-filling similar to that now in progress at the head of the lake. When the number of torrential streams that descend the valley wall is considered, the amount of lake-filling which this stratum represents is not excessive. These streams have formed deep gorges, having not only removed much drift, but also cut deeply into the shale. The material thus removed seems ample to make this deposit.

The upper series of coarse sediments.—A much more difficult problem is presented by the sand and gravel series, sandwiched between the two clay beds, and covering an area whose length north and south is known to be over one and a quarter miles. Some widespread change in condition is here represented, indicating a stage during which clay deposit was interrupted, apparently after the ice-dammed lake ceased to offer opportunity for deposit of lake clay, and before conditions appeared which permitted the accumulation of the later lake clays.

This period of interruption of lake clay deposit must have been one in which, at the site of the wells, the conditions were either those of a shallow lake or else of absence of lake water. Both the coarseness of the sediment and the abundance of organic remains indicate this. It is inconceivable that at a distance of three-eighths of a mile (the distance from the outermost well to the nearest valley wall) gravel and sand could be deposited in a lake from 56 to 118 feet deep, especially at a point remote from the mouth of any stream. It is inconceivable, also, that gravel and sand could be deposited in such a lake over so wide an area. Nor does it seem probable that such a large number of logs would be accumulated in lake deposits. The chance discovery of seven logs in boring thirteen six-inch wells through this sand-gravel series indicates a large number of logs in the series. This point becomes all the more striking from the fact that only two logs were found in the recent lake clays, and both of these near the sand-gravel series, while no logs were encountered in the ice-dammed lake clays.

Professor Penhallow has determined the two specimens of wood preserved as follows: (1) South Well, 30–35 feet in clay, *Pinus rigida;* (2) Millard Well No. 1, 50 feet, gravel, the common tamarack, *Larix americana.* Dr. Dall reports that the mollusca belong to the following genera: Valvata, Planorbis, Amnicola, and fragments of Pisidium or Sphœrium. These are

all of the same nature, namely fresh-water, and such as are found in the confervæ or other fine-textured vegetable matter, such as grow in quiet places in the course of brooks, or in ponds or lakes at the mouth of brooks. They would hardly be found in the unsheltered waters of a large lake like Lake Erie.

Correlation of coarse sediments with Iroquois stage.—The evidence seems conclusive that these sands and gravels were either shallow-water, lake-margin deposits or else stream-made land deposits, and that they were succeeded by lake conditions. In seeking for an explanation of these phenomena, land-tilting seems the only rational hypothesis. It is a well-known fact, as clearly shown by Dr. Gilbert, that the land has been tilted in this region since the deposit of the beaches of the Iroquois shore line. The Iroquois lake stage immediately succeeded the stage of ice-dammed lake in Cayuga Valley. Therefore these sands and gravels are in the right position for correlation with the Iroquois beach stage.

In a letter to me Dr. Gilbert supplies the following information: Correlating the upper bar at Richland Junction (563 feet) with the lowest bar at Weedsport, there is a gradient of 2.9 feet per mile. Correlating the upper Richland bar with the lower cut terrace at Montezuma, there is a gradient of 2.6 feet per mile. Correlating the upper Richland bar with a bar at Cayuga, there is a gradient of 2.7 feet per mile.

The lines on which these measurements are made do not precisely correspond with the direction of greatest slope of the plane of deformation, but I judge that the line from Union Springs to Ithaca makes about the same angle with the direction of greatest slope, so that these figures might be applied without correction. A correction for direction would increase the estimates for gradient.

From Union Springs, where the Iroquois beach disappears beneath Lake Cayuga, to the site of the wells is approximately twenty-nine miles; and, taking 2.7 feet per mile as a gradient, the Iroquois shore line might be expected to appear at Ithaca at a depth below present lake-level of about 78 feet. Several of the wells passed through coarse material at this depth, and in several of them the coarse materials reach a much greater depth than this. On the other hand, the records of four of the wells show that the sands and gravels were passed through before that depth was reached. In his letter Dr. Gilbert makes this further statement:

> From Richland northward to Adams Center the gradient is 4.3 feet per mile, and north of Adams Center it is still steeper. So it is possible that a correction might advantageously be applied to southward flattening of gradient.

Some such correction, the exact amount of which is not clear, would seem to harmonize better with the distribution of the gravels as revealed by the well sections.

Several facts, as follows, seem to warrant correlation of these deposits with the Iroquois stage: (1) the difficulty of otherwise explaining the sand-gravel series; (2) the evidence of coarseness of material, and of plant and animal remains, all of which point either to land or shallow-water conditions; (3) the position of the series, resting on deposits which appear to have been completed just before the Iroquois stage; (4) and the fact that their position is approximately at the level to be expected on the theory of formation during the Iroquois stage. No facts opposing this correlation are known, and no other rational explanation suggests itself. It is therefore proposed as an interpretation of the phenomena.

SUMMARY OF EVENTS.

On the basis of these interpretations, we have revealed the following postglacial history of the Ithaca delta: First moraine was formed while the ice-front stood in a deep lake, in which the morainic material was largely assorted. After this stage there was a long period of lake clay deposit in an ice-dammed lake whose area was expanded, while its level fell by successive drops to lower levels as the steady melting back of the ice-front discovered lower and lower outlets to the north. In this lake there was floating ice, but little, if any, animal life. When the Mohawk outlet was finally discovered the ice-dammed lake nearly, if not quite, disappeared from the site of the artesian wells. The land surface at the site of these wells was then from 60 to 120 feet below the present delta surface; but, owing to the depression of the land in the north, the lake waters either could not then reach this far, or, if they did, produced only a shallow lake. At this stage trees grew and mollusca thrived, while a series of sand and gravel layers were laid down whose depth in the several wells varies from 20 to 70 feet.

Elevation of the land in the north tilted the basin of Lake Cayuga faster than the deposit of sand and gravel was made, ultimately covering the coarse deposits with lake water. Some of the sand and gravel may be due to the work of the lake waves as the tilting of the land caused an encroachment of Lake Cayuga farther and farther south. The fact that the present surface of the delta contains no sand and gravel excepting near the stream mouths, may be explained as follows: (1) the levelness of the delta; (2) the recency of the delta—it is still so swampy at the well sites that it is flooded at least once each year; (3) the fact that the streams now bring less material, having already cut through the drift into the rock.

SOURCE OF THE ARTESIAN WATER.

It is believed that the source of the water in the upper gravels is the alluvial fans opposite the mouths of the streams that descend to the Ithaca delta. Into these fans much of the stream water sinks, in some cases entirely disappearing at all times excepting in periods of flood. It is not absolutely certain that the gravels of the alluvial fans are continuous with the sand-gravel series encountered in the shallower artesian wells; but this is to be expected, since the conditions which favor the deposit of coarse sediment must have existed continuously near the mouths of the streams that descend the hill slope. Some such source near at hand is indicated by several facts: (1) a reported variability in volume; (2) the moderate pressure of the wells, which in some cases barely forces the water from the ground; (3) the composition of the water, which indicates a shorter underground journey than that of the water in the deep wells; (4) the marked difference in composition and purity of the water from various wells.

For the water found in the deeper sands and gravels the source is believed to be the moraine which occupies the Cayuga Valley from the divide nearly to the well sites, a distance of over eleven miles. Numerous streams descend to this moraine, supplying much more water for percolation than the mere rainfall. The moraine is to a very large degree made of sand and gravel, offering the best of conditions for the entrance of water. The hardness of the water and the temperature (52° in August and December) both indicate a long underground journey; and the great pressure, which forces from one of the wells a steady volume of 300,000 gallons a day, also indicates some fairly distant source. To account for the pressure observed it is necessary to find a source much higher than the well sites. No such source is to be found to the north because the lake occupies that region; to the east and the west rise high hills in which are nearly horizontal strata of shale and sandstone. This leaves the moraine to the south as the only possible source of the water; and this source is not only ample, but, if the above interpretation of the well sections is correct, there is a direct connection between the surface moraine and the buried moraine gravels which supply the water.

R. S. TARR.

ITHACA, N. Y.